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Conceptual design of a thorium supplied thermal molten salt wasteburner

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DTU Nutech
Center for Nuclear Technologies

The Project

- Me: Troels Schönfeldt: PhDc - Advanced cold neutron moderators @ DTU Nutech and ESS Neutronics
- 168 hours/week. A PhD study is 37.5 hours/week (=> 77.7% spare-time)… So we started a company
- **Seaborg IVS:**
  - We now consist of 10 unpaid physicist, chemists and engineers
  - We focus on nuclear reactor technologies, with special focus on molten salt reactors and thorium
- Here you will be presented with our, still very preliminary, **Seaborg WasteBurner, the SWaB**

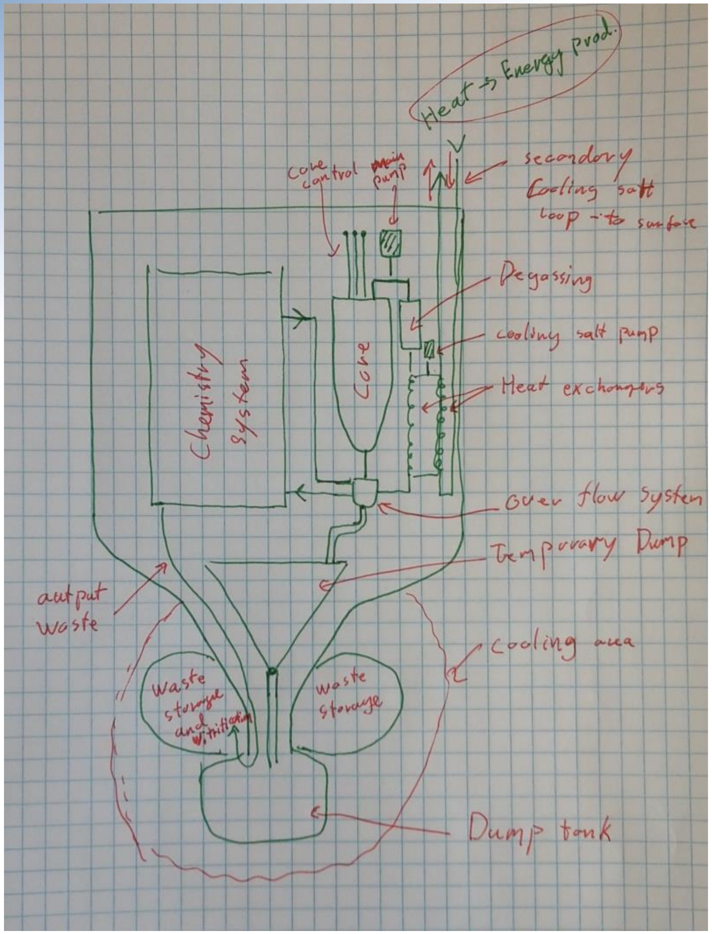
Kickoff

- In December 2014 we were invited to join the *"Feasibility Study for the Development of a Pilot Scale Molten Salt Reactor in the UK"*, by:

ENERGY PROCESS DEVELOPMENTS LTD.

- The SWaB design - a single salt thermal molten salt wasteburner
- The SWaB is currently under evaluation by UK experts
- Also, it turns out that 130.5 hours/week of spare times is not really a lot

Our constraints



Early drawing of the "bottle".

1: No weapons!
- No separation of Pu/Pa from U
- Highly "denatured" U and Pu
- Decreasing weapon "quality"

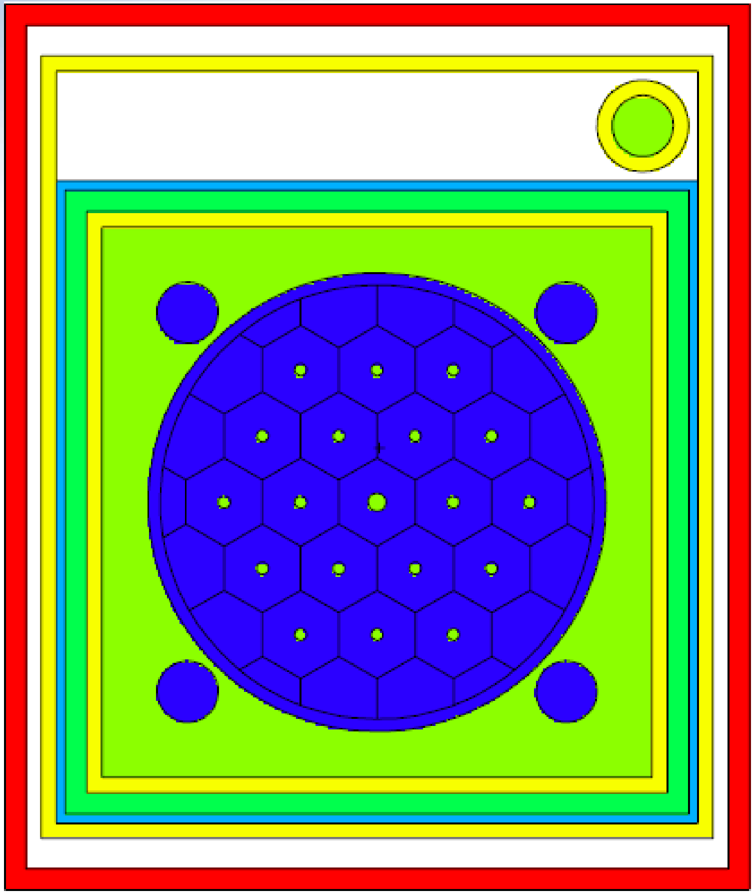
2: Inherently safe
- Rely on physics
- Any active system must be redundant

3: Wasteburner
- Negative net TRU production
- Evolve towards the closed thorium fuel cycle

4: Thermal spectrum operation
- Because it has tremendous advantages
- Inefficiency of TRU burning should be compensated for by enhanced neutron economy

5: Modular (Economical):
- decrease construction/decommission cost
- Shipyard style manufacturing - mass-production

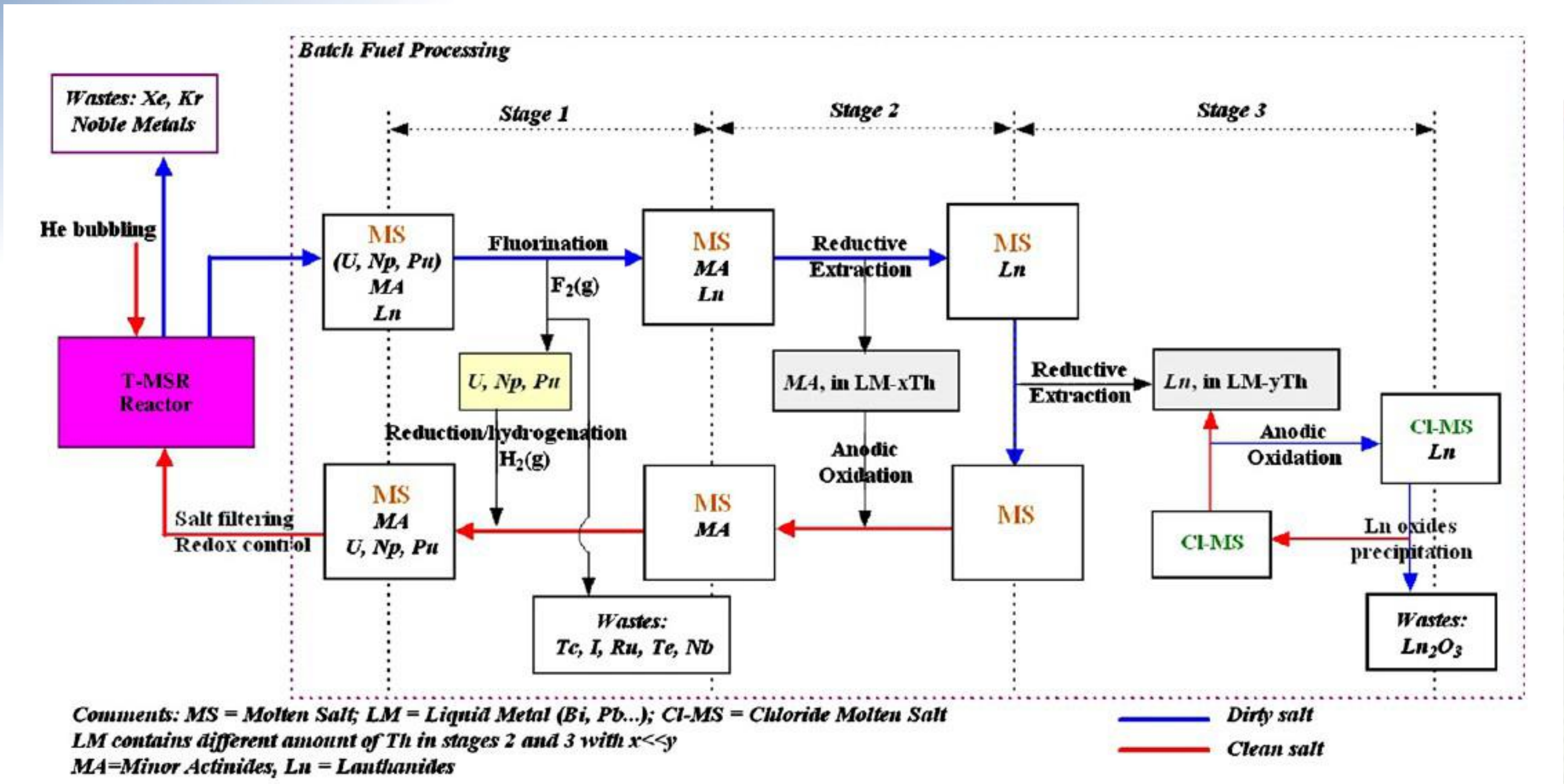
The "product"



Reactor class:

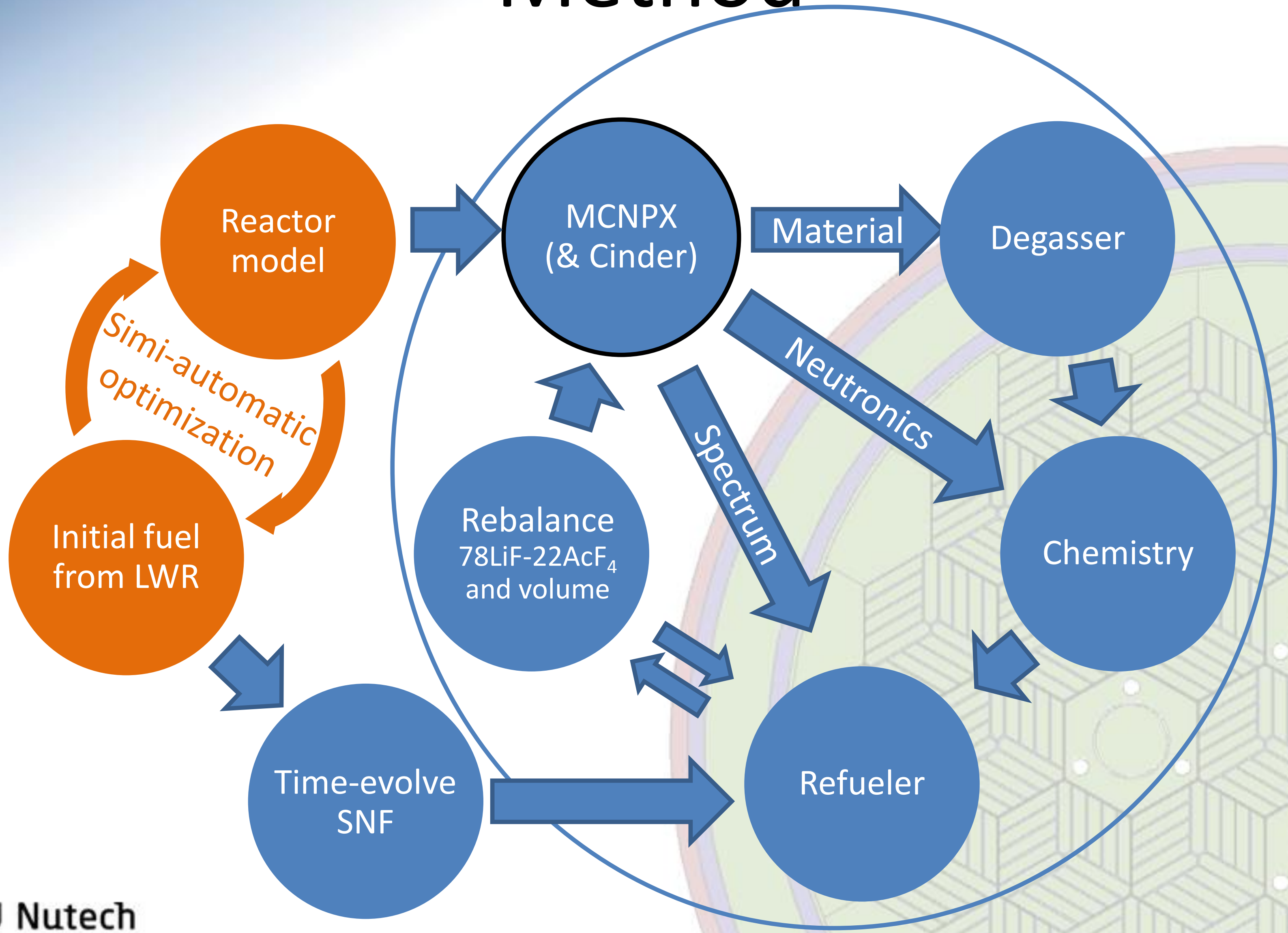
The Ultra Compact, Small Modular, Single-Salt, Integrated Thick-Blanket, Thorium Supplied, Thermal-Epithermal, Denatured, Integral Continues, Very High Temperature, Molten Salt Wasteburner Reactor.

Chemistry



S. Delpech et al., Reactor physic and reprocessing scheme for innovative molten salt reactor system.
Journal of fluorine chemistry, 2009

Method



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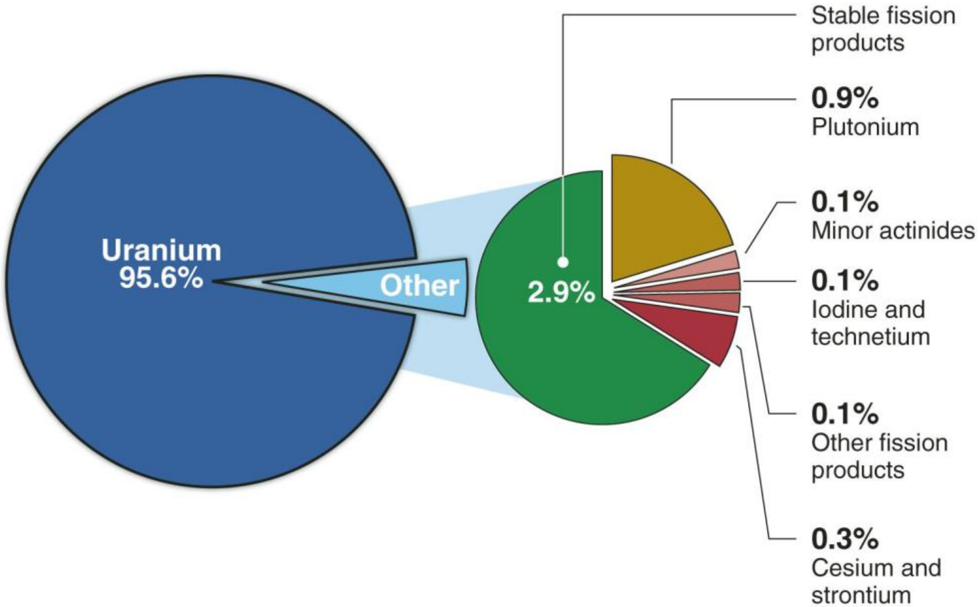
Initial fuel and alternatives

	processed waste	4.5% ^{235}U	19.99% ^{235}U	93% ^{235}U	100% ^{239}Pu
^{232}Th fraction	86.7%	6.9%	73.3%	93.9%	97.6%



Source: GAO analysis of DOE data.

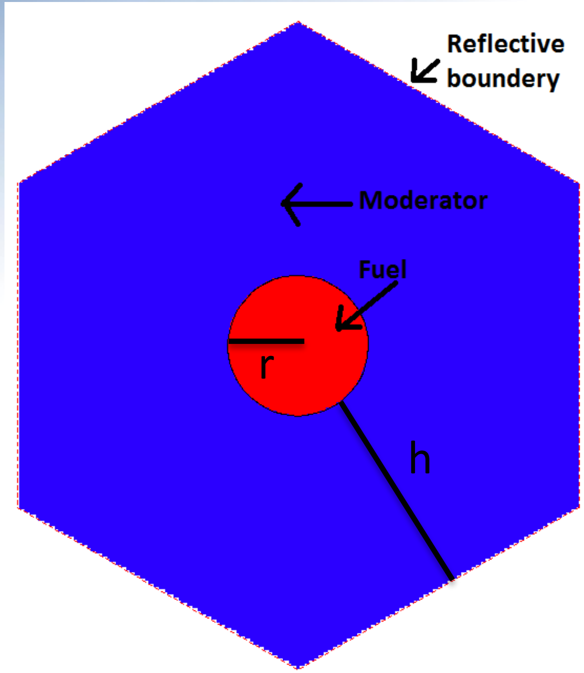
Flame reactor:

SNF -> Fluoride salts and removes:

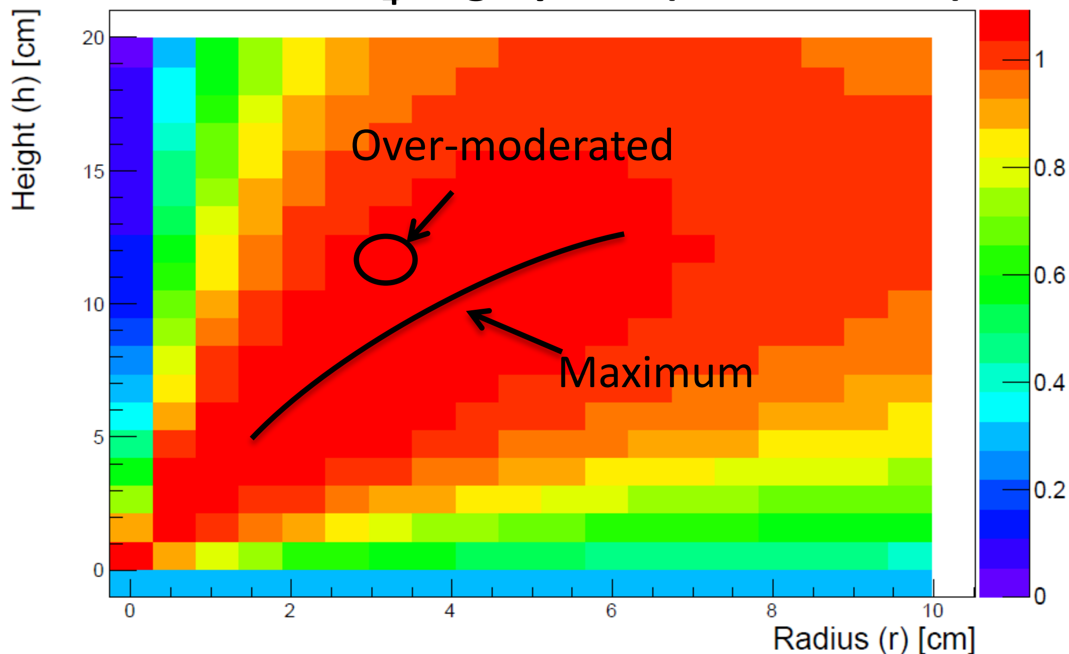
- 99.1% U (as UF_6)
- 0.1% other Ac
- 99% FP (extracted)

Initial fuel (10 year storage):
45% U (~1.3% enriched)
45% Pu (~68% fissile)
5% FP (only non-gasses)
5% minor Ac (mainly Am)

Salt and moderator



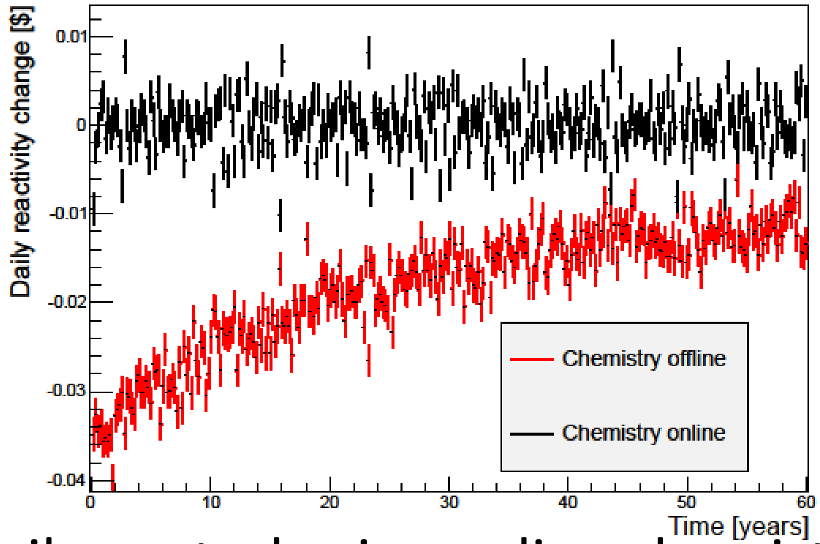
78LiF-22AcF$_4$ in graphite (700°C-900°C)

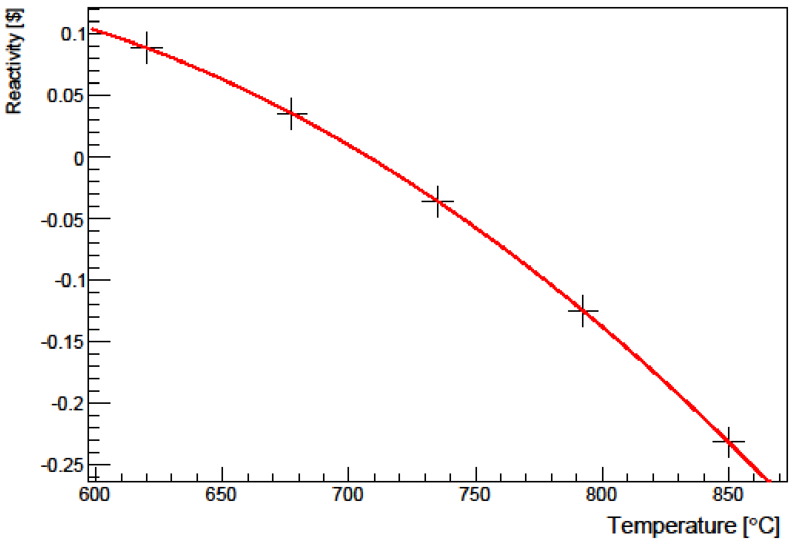


- Iterative optimization of geometry and spent fuel to Th ratio (Ac => xTh+yAc$_{SNF}$ optimized to Keff$_{max}$~1.05)
- Using this tool, we were able to analyze several moderator and carrier salt candidates in a matter of days.

Control

1: Huge “instant” negative response, mainly from salt density change.
2: Small “slow” positive response from graphite heating. (Problematic)



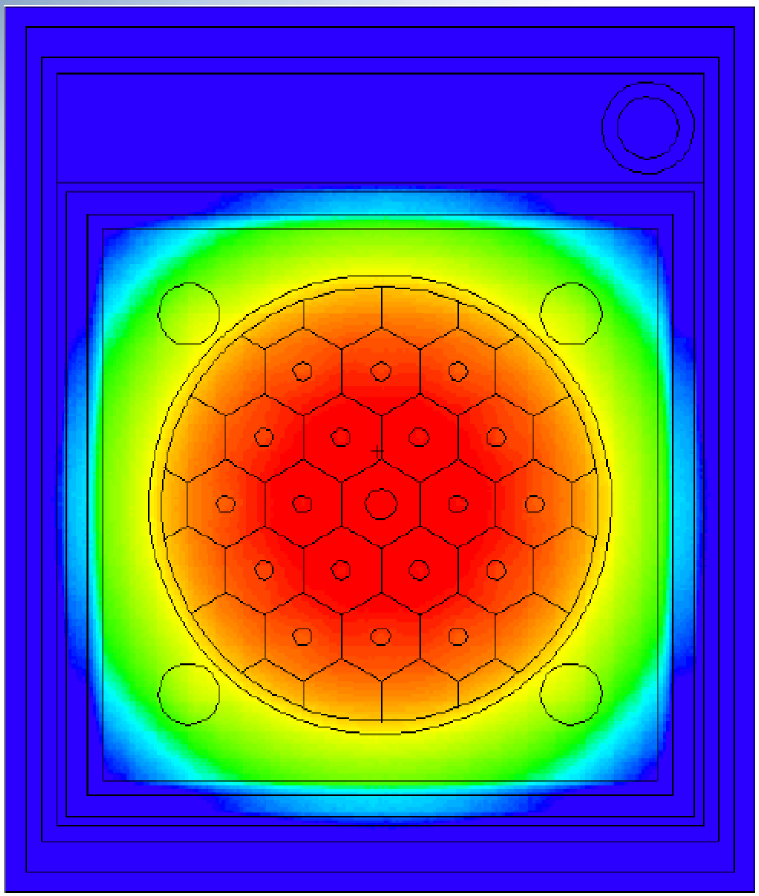


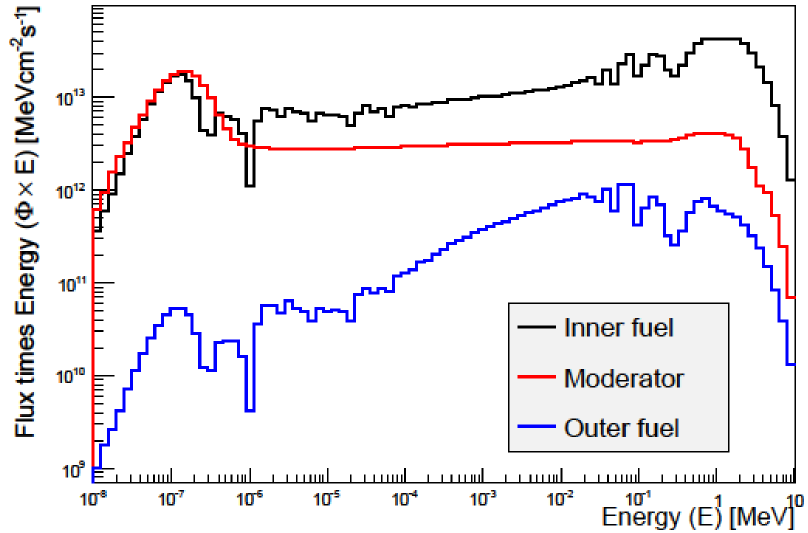
Daily control using online chemistry.

Hourly control using 4 graphite fine-tuning rods (Δkeff=0.88$=254 pcm)

Absorbing control rods for full shutdown only (= better neutron economy)

Core



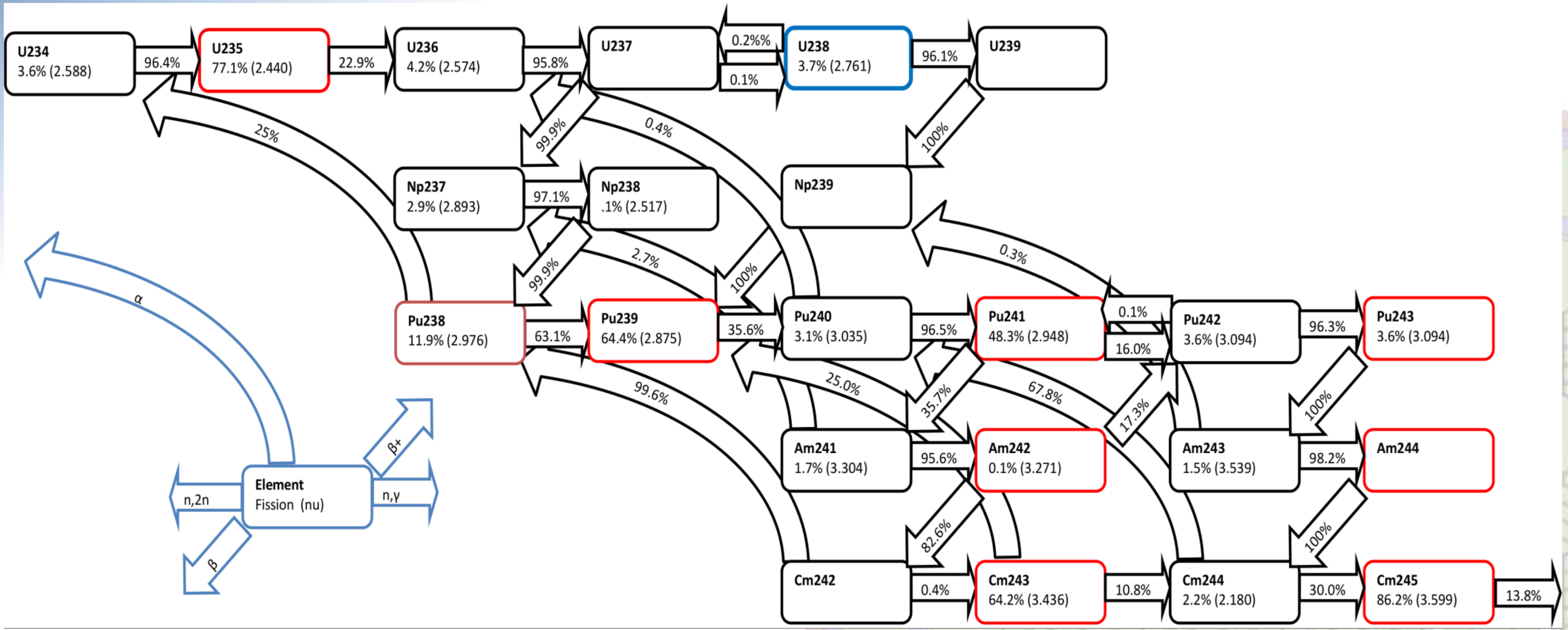


Thermal-epithermal core
Epithermal-fast blanket

Pot outer dimension: 190x190x340 cm^3
Blanket thickness: 15-22 cm
Moderator: **Graphite** (r=75 cm, l=300 cm)
Operation temperature **700°C-900°C**
Flow speed: 38.1 l/s
Salt volume: **~6 m^3** (~5 m^3 in core)
Salt composition: **78LiF-22AcF$_4$** (99.95% ^{7}Li)

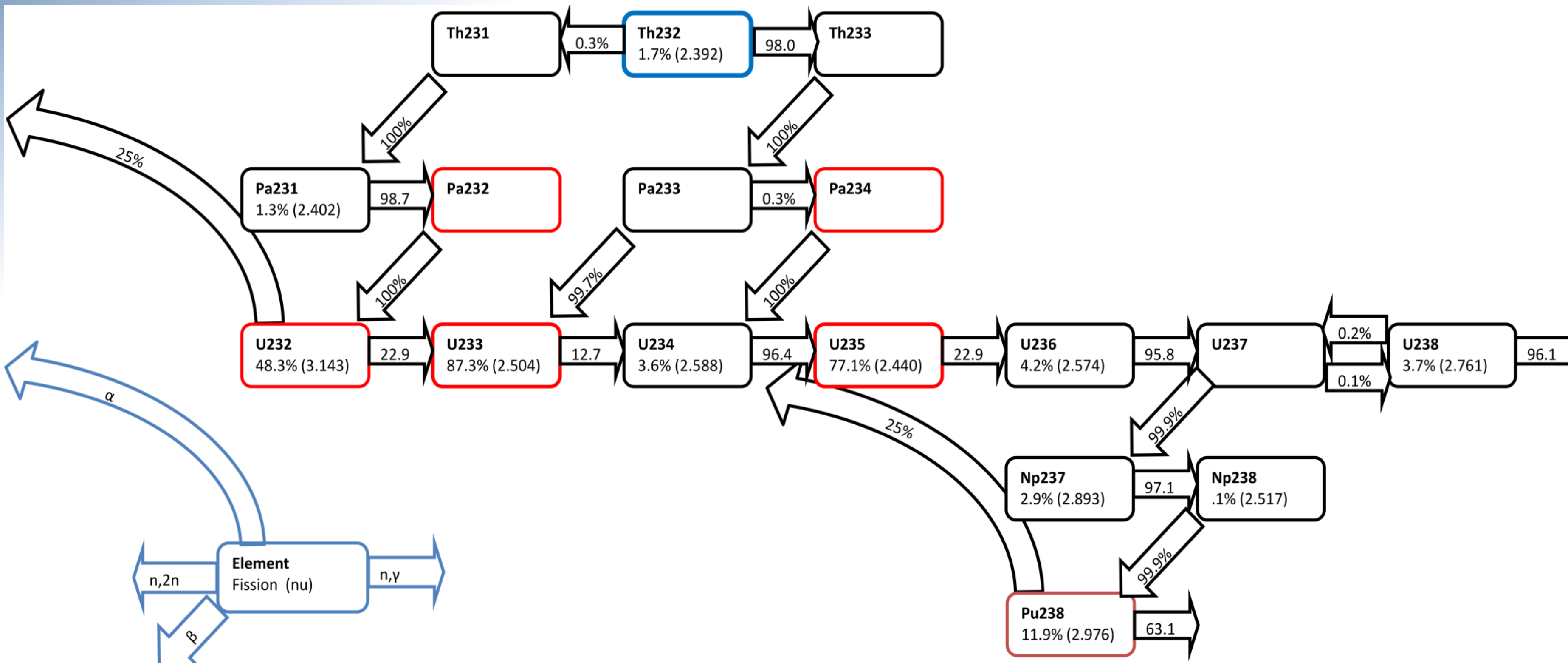
- 100Ac ~ **87Th+6U+6Pu+1Ac$_m$** (starting)
- Melting point <568°C
- Salt evaporation starts: >1300°C

U-cycle



Running the cycle with our (thermal-epithermal) spectrum utilizes **83.1%** of the fuel and produce **16.9%** americium waste – but **eta=0.88** (sustainable is eta>>1)

Th-cycle



Running the cycle with our (thermal-epithermal) spectrum utilizes virtually all the fuel and produce **4.56 ppm** americium waste and **eta=1.06** – however…

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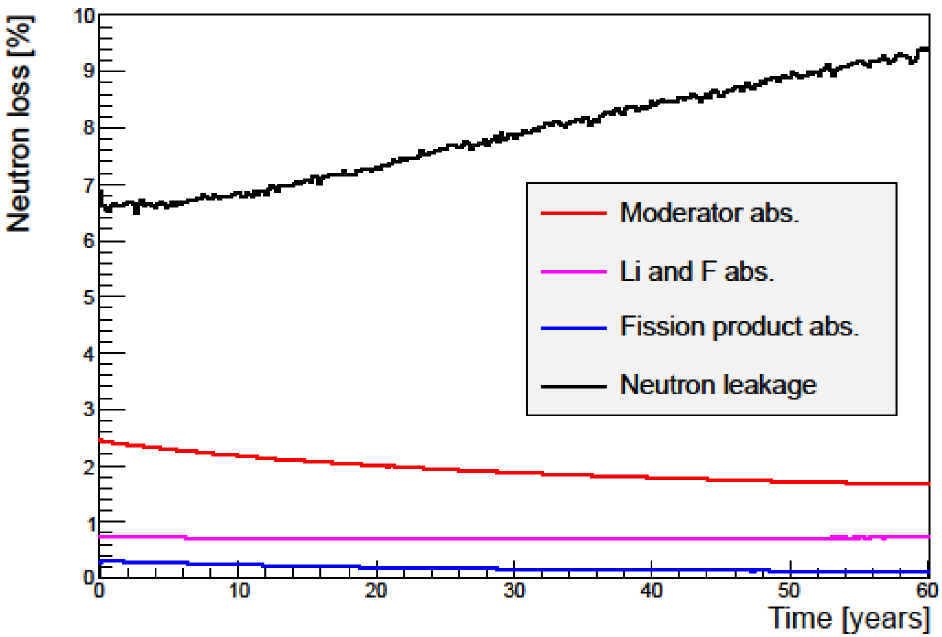
Neutron loss

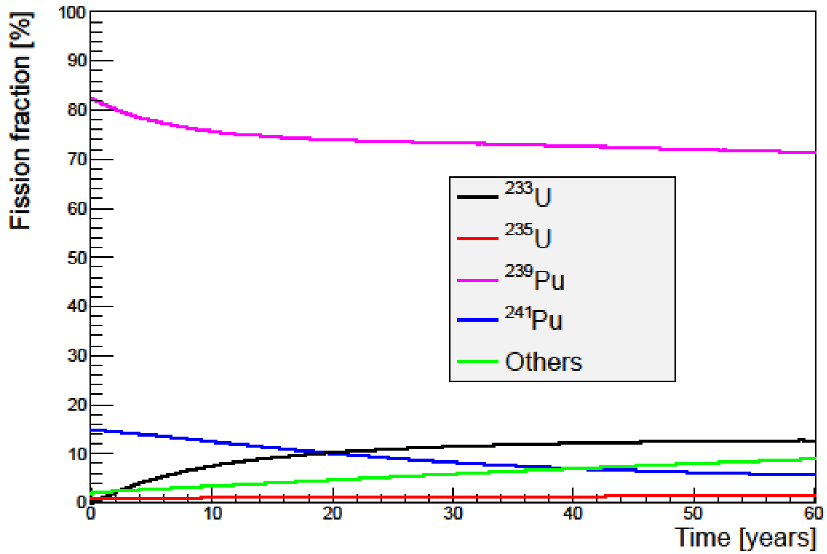


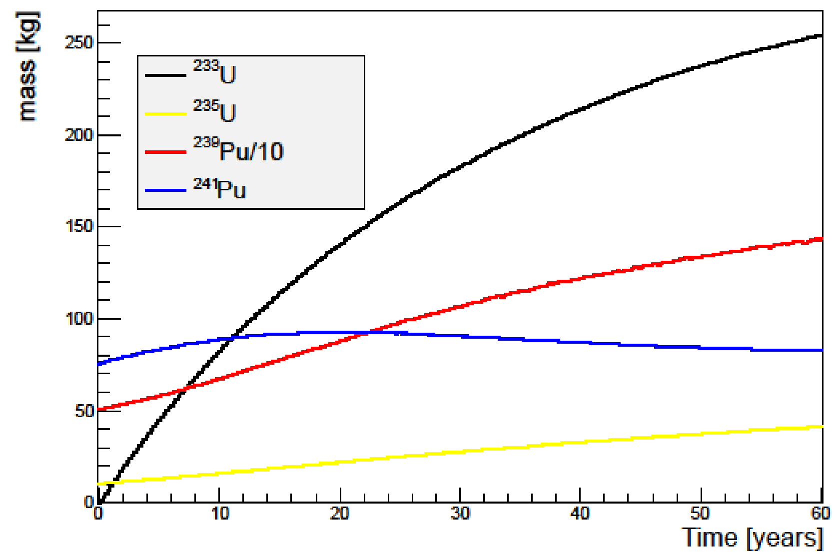
The changing leakage over time, is caused by significant inventory changes from "over-fueling" (and Th removal) to keep the core critical.

Actinide component	Initial	30 years	60 years
Thorium	86.7%	59.6%	39.9%
Uranium	6.3%	21%	32%
Plutonium	6.3%	16%	23%
Minor Ac	0.6%	3.0%	4.8%
Fissile Pu/Pu	**67.8%**	**53.1%**	**48.5%**

Our thorium cycle has eta=1.06
But we **lose 10-13%** neutrons.

Fissile Material





60 years, at 50 MW_{th}:

Net negative transuranic production of ~1 ton!

We do not have an underlying closed thorium fuel cycle.

But with the production of ^{233}U we are getting closer.

Next step: SWaB -> CUBE

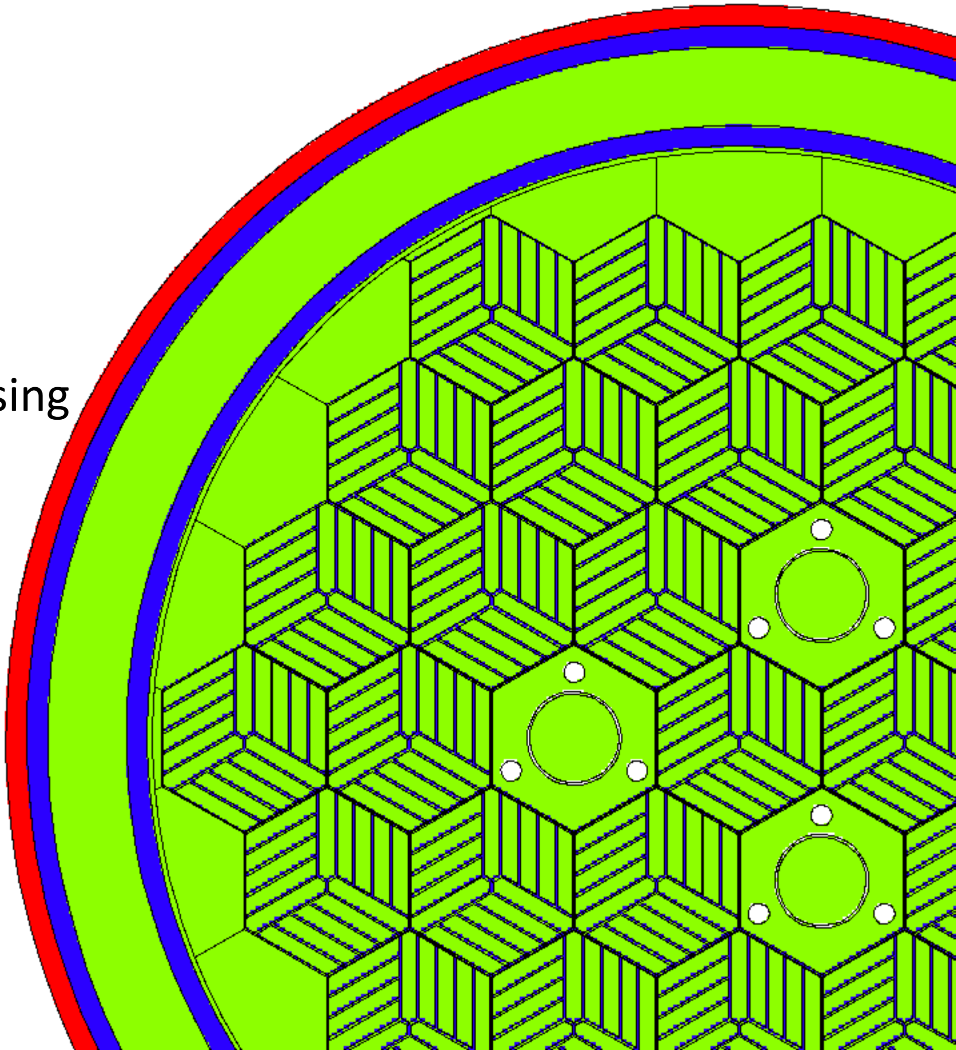
Seaborg WasteBurner -> Compact Used fuel BurnEr

Fix reactivity feedback from graphite expansion
- graphite slabs instead of salt pipes

Increase fine-tuning rods reactivity span
- move rods to a more central position

Reduce Pu (and Ac_m) inventory
- minimize salt volume (double blanket?)
- optimize moderator configuration
- remove Am online
- increase UF6 evaporation in fuel processing

Increase neutron economy
- reduce leakage (~~ultra~~ compact)
- add outer reflector



Funding needed for two activities:

System engineering and multi physics

Chemistry system design and verification

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